

AD-A118 707

ALBERTA UNIV EDMONTON DEPT OF CHEMISTRY

F/G 7/4

VIBRATIONAL SPECTROSCOPY OF THE ELECTRODE-SOLUTION INTERPHASE. --ETC(11)

AUG 62 S PONS, T DAVIDSON, A BELICK

N00014-A2-G-0017

UNCLASSIFIED TR-10

NL

101
101

END
THIS
FILMED
10 82
DIA

AD A118707

DTIC FILE COPY

12

OFFICE OF NAVAL RESEARCH
Contract N00014-82-G-0017
Task No. NR 359-718
TECHNICAL REPORT NO. 16

Vibrational Spectroscopy of the Electrode-Solution Interphase.IV.
FTIR: Experimental Considerations.

By

Stanley Pons, Timothy Davidson, and Alan Bewick*

Prepared for Publication in

Analytical Chemistry

University of Alberta
Department of Chemistry
Edmonton, Alberta, Canada
T6G 2G2

*Department of Chemistry
The University
Southampton, U.K.

August 18, 1982

Reproduction in whole or in part is permitted for
any purpose of the United States Government

This document has been approved for public release
and sale; its distribution is unlimited.

DTIC
ELECTE
S AUG 30 1982 D
H

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS FOR USE OF THIS FORM	
1. REPORT NUMBER 16	2. GOVT ACCESSION NO. AD A118707	3. DEPARTMENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Vibrational Spectroscopy of the Electrode-Solution Interphase. IV. FTIR: Experimental Considerations.		5. TYPE OF REPORT & PERIOD COVERED Technical Report # 16	
6. AUTHOR(s) Stanley Pons, Timothy Davidson, and Alan Bewick		7. PERFORMING ORG. REPORT NUMBER N00014-82-G-0017	
8. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Chemistry University of Alberta Edmonton, Alberta, Canada T6G 2G2		9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Task No. NR 359-718	
10. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Chemistry Program - Chemistry Code 472 Arlington, Virginia 22217		11. REPORT DATE August 18, 1982	
12. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 27	
		14. SECURITY CLASS. (of this report) Unclassified	
15. DISTRIBUTION STATEMENT (of this Report) This document has been approved for public release and sale; its distribution unlimited.			
16. DISTRIBUTION STATEMENT (of the abstract entered in block 20, if different from Report)			
17. SUPPLEMENTARY NOTES			
18. KEY WORDS (Continue on reverse side if necessary and identify by block number) Electrochemistry, Spectroelectrochemistry, Reflection Spectroscopy, FTIR Infrared Spectra			
19. ABSTRACT (Continue on reverse side if necessary and identify by block number) The experimental details for the gathering of high quality infrared spectra in the electrode-solution interphase are given.			

DD FORM 107 1073 EDITION OF 1 NOV 65 IS OBSOLETE
GPO 5102-11-010-5501

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

82 8 27 059

ABSTRACT

The experimental considerations necessary to effect successful recording of in situ vibrational spectroscopy at the electrode-solution interface are described. In this work, the Fourier transform infrared spectrometer is used.

VIBRATIONAL SPECTROSCOPY OF THE ELECTRODE-ELECTROLYTE INTERFACE.

IV. FOURIER TRANSFORM INFRARED SPECTROSCOPY:

EXPERIMENTAL CONSIDERATIONS

Stanley Pons* and T. Davidson
Department of Chemistry
University of Alberta
Edmonton, Alberta, Canada
T6G 2G2

and

A. Bewick
Department of Chemistry
The University
Southampton, Hampshire
SO9 5NH
U.K.

* To whom correspondence should be sent.

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	



DTIC
ELECTE
JUN 3 1985
H

3

Although the use of infrared spectroscopy as an *in situ* probe for observing interfacial phenomena during electrochemical experiments has been attempted many times in the last 20 years, it has only been in the last three years that high quality reproducible spectra have been routinely obtained. This has been because of (a) the successful coupling of electrode modulation techniques to the optical signal (1), (b) the exploitation of the multiplex advantage and high throughput of Fourier transform spectrometers (2), and (c) the use of more sophisticated techniques such as polarisation modulation (3). As a result, investigations such as the study of adsorbed hydrogen on platinum and rhodium (4,5), the structure of intermediates in electrocatalytic oxidations (6), the study of organic ion radical intermediates (7), the adsorption of acrylonitrile (8), the platinum interface in organic electrolytes (2,9), and the structure of water at various electrode surfaces (1,10) have been reported.

It is the purpose of this paper to define the experimental techniques and apparatus required to obtain such results by using Fourier transform infrared methods. Although time resolved spectroscopy is possible using the techniques described herein, we will limit our discussion to near steady-state measurements. Thus the basic approach is to apply a potential step to an electrode, wait for steady state conditions to develop, and take one or more rapid infrared spectra. The potential is then returned to a base potential, and the procedure repeated. The entire cycle is repeated and the spectra are signal averaged to the desired signal-to-noise level. Appropriate ratioing of the 2

4

sets of spectra with subsequent subtraction gives the desired result.

EXPERIMENTAL

Spectrometer

The instrument used in our recent work has been the Nicolet 7199 Fourier transform infrared spectrometer. To perform these experiments, the machine should have the following features:

- (1) The ability to store, and signal average subsequent spectra, in at least three separate data files. The software should be flexible enough to specify which file is to be used for a given spectrum.
- (2) An output trigger pulse (preferably TTL or CMOS compatible) designating the beginning of data collection by the A/D converter of the instrument on each scan.
- (3) Spectral ratioing and subtraction capability.
- (4) Capability to handle mid-IR fast detectors with minimum D^* values of 1×10^{10} , such as mercury-cadmium-telluride 77 K solid state units.
- (5) Sample compartment sizes large enough to hold comparatively large cells mounted on adjustable reflection attachment optical tables.
- (6) Reasonably fast data collection times.
- (7) Resolution of 8 cm^{-1} or better.

Data Presentation

The most convenient form in which to present spectra is as a difference in infrared transmission of the cell at each of the

two electrode polarization states. This difference will then be due to changes in the interphase brought about by the differences in potential, the optical properties of the rest of the cell remaining constant. In terms of the measured reflectivities at the two potentials, R_1 and R_2 , this difference in transmission can be written as $R_2/R_1 - 1$, a quantity which is readily obtained using software normally provided with commercial FTIR spectrometers. In practice, it is most convenient to calculate $R_2/R_1 - 1$ as $R_2/R_1 - R_1/R_1$. This latter quantity is simply the difference between two single beam spectra, each of which has been ratioed to the chosen reference state R_1 . Presentation of the spectra in this form is thus equivalent to the $\Delta R/R$ presentation used in EIRS ($\Delta R/R$ is equivalent to $(R_2 - R_1)/R_1$).

Electrochemical Instrumentation

The potential was controlled at the working mirror electrode by a Hi-Tek Instruments DT2101 potentiostat driven by a PPR1 waveform generator. The Nicolet computer supplied a TTL pulse to a BNC connector on the rear panel as each new scan was initiated. This pulse was used to trigger the waveform generator via a 74190 TTL up-down counter. (See discussion.)

Electrodes and Cell

Electrodes (Chemical Electronics Associates, 333 South County Road, P.O. Box 3120, Palm Beach, Fla.) were constructed from a 2 mm thick - 7 mm diameter disk of the desired material affixed to the end of a 7 mm - 135 mm brass rod which had been heat/press fitted into a Kel-F sleeve (o.d. = 9 mm). A loose fitting Kel-F sleeve at the rear of the electrode assembly was

made to butt a rubber gasket against the fixed sleeve by a nut at the end of the assembly to seal it into the cell barrel. The brass rod was covered with a thin layer of epoxy before sealing it into the Kel-F sleeve to prevent any chance of leakage of solution between the electrode and the sleeve. Electrodes prepared in this manner are very stable mechanically and chemically in most solvents and electrolytes for several months. For instance, we have used 1 M sulfuric acid, 1 M perchloric acid, acetonitrile, methylene chloride, dimethylformamide, dimethylacetamide, and dichloroethane for extended periods without degradation of electrode performance.

Electrodes are typically polished by mounting in a sturdy aluminum jig to maintain perpendicular contact with the polishing pad, or on a commercial polishing machine. With reasonable care, electrodes flatter than 1/2 at 5 microns were obtainable using these rather simple techniques.

Even though the electrodes are reasonably flat, it is necessary to take additional care to assure that the face is parallel to the optical window, so that a uniform solution layer thickness will exist there. This is accomplished by allowing the optical window to be bonded to its ground glass sleeve with both sleeve and electrode in place in the cell and with the window resting on the face of the mounted electrode, pressure being maintained against the window simultaneously to keep it absolutely flat against the electrode face (Figure (1)). The electrode, window cap, and cell body were scribed to maintain reproducible realignment in subsequent experiments. When the window was prepared in this manner, typical fluctuations in gap



size of 20.05 microns were obtained in measurements from side to side across the electrode face using the integrated extinction coefficient of the acetonitrile C≡N stretch fundamental absorption band as a measure of the gap thickness.

The cell (Chemical Electronics Associates, Inc.) was similar to that described by Bewick et al for use in electrochemically modulated infrared reflectance spectroscopy (EMIRS) (11). It was 125 mm in overall length without the electrode mounted, and held 50 cm³ of solution. The optical window was mounted on a T 24 female ground glass joint. When in place, the working electrode disk may be pushed up flush to the window. A Luggin reference capillary was mounted with its tip close to the window where the electrode face rests. The Luggin is connected through a ground glass stopcock to the reference electrode compartment. A platinum wire loop was mounted such that the loop was coaxial with the mounted working electrode to serve as the secondary electrode. Purge gas inlet and outlet connections were made at the bottom and top of the main cell body, and the working electrode mounting tube was located at the rear.

A small platinum wire to be used as a subsidiary reference electrode may be mounted through the Luggin tube just below the stopcock to provide a low impedance path and reduce high frequency interference. When used, it was connected through a 0.1 μF capacitor to the normal reference electrode.

Reflectance Attachment

The converging beam of radiation through the sample compartment of the spectrometer must be interrupted and made to

reflect from the electrode surface at a 45° angle.

Subsequently, the beam must be returned to its original path as closely as possible so as not to affect the purpose of the focussing optics of the output detector section of the spectrometer. Several designs for an apparatus to perform this function are possible. We have used a modified version of an apparatus described by Marrick (12).

Polarisation of the radiation was effected by mounting a KBr substrate transmission polarizer (Cambridge Physical Sciences, Cambridge, England, Type IGP228) in the beam either in front of or behind the cell. The polarizer was mounted in a calibrated housing that could be rotated so that any polarization angle could be conveniently chosen.

Solvents and Chemicals

Due to the extremely high sensitivity of the method, it is necessary to use very pure solvents and electrolytes for routine investigations. We have found that the use of HPLC grade commercial solvents are suitable for most organic intermediate studies (7), while further purification of these solvents is usually required for sensitive adsorption or double layer studies (9).

The drying of supporting electrolytes, such as lithium perchlorate or tetraalkylammonium salts should be effected with a vacuum oven for at least 24 hours at the maximum possible temperatures. Transfers of electrolytes and solutions to the cell should be made in a dry atmosphere.

RESULTS AND DISCUSSION

As an example of a typical experiment, it was desired to record the spectrum of the benzophenone ketyl species formed by the one electron reduction of benzophenone at a platinum electrode. A 10 mM solution of benzophenone in degassed anhydrous 0.10 M tetrabutylammonium tetrafluoroborate was used. The electrode was placed flush against the cell window, and allowed to relax against the rubber gasket on the electrode assembly. Using the 2220 cm^{-1} acetonitrile band, the solution thickness was found to be about 5 microns, as determined by the relation

$$d = \frac{2A \cos \theta}{\epsilon C}$$

d is the solution thickness, A is absorbance, ϵ is the extinction coefficient, C is the concentration of the absorbing species, and θ is the angle of incidence at the reflecting surface. The polarizer was set to pass the component of light that had its electric field vector parallel to the incidence plane, so that the field would have a non-zero magnitude at the electrode surface.

The "begin scan" TTL pulse available from the computer of the FTIR spectrometer was used as input to a 74190 binary up counter whose binary output had initially been preset to binary output 15 (1111). The MSB output of the counter was connected to the "start" TTL input of the FPR1 waveform generator so that the latter executed one waveform sequence on every 0 to 1 transition

from the counter, i.e. every 16 scans of the spectrometer. The waveform generator was set to give a rectangular pulse of 9 s duration (about 1 second longer than the spectrometer requires to scan 8 spectra) such that the electrode potential was taken to -2.50 V (Ag/Ag⁺ reference) for 9 s then returned to the base value of -1.70 V until the spectrometer initiated the 17th scan and the complete sequence was repeated.

A software program was written to perform eight scans, of which only the last four were co-added and saved in a reference file. This operation allowed about four seconds (the first four unused scans) for the cell to come to a steady state. The program then called for eight more scans to be made, again discarding the first four, but this time storing the co-added last four in a sample file. This operation was repeated 10 times so that a total of forty co-added spectra resulted in the reference file and the same in the sample file. This program was interfaced synchronously to the waveform generator through the "begin scan" pulse and the 74190 counter circuitry. Thus the spectra were gathered at the approximate points indicated in Figure (2). An example of the spectrum computed from this data in the manner described in the experimental section is shown in Figure (3).

Basically, the peaks extending upwards correspond to the removal of benzophenone substrate, at the expense of the formation of ketyl (downward extending peaks). A full description of this spectrum has been repeated (7).

The spectra in Figures (4) and (5) were obtained in a similar manner. Details are provided in the figure legends.

Higher sensitivity was needed to observe changes in the population of species as the double layer structure was changed at a platinum electrode. A thinner solution layer (0.75 microns) and 100 averaged spectra at each potential state was utilized. The electrolyte was 0.10 M tetrabutylammonium tetrafluoroborate. The resulting difference spectra are shown in Figure (6). The effect of added water for the same experiment is shown in Figure (7). These spectra have been interpreted elsewhere (6).

It is clear from the spectra shown that the technique has the sensitivity to detect changes approaching 10^{-6} M in experiments collecting data from 100 scans at each potential, the total experimental time being about 10 min. Thus the method seems well suited for the obtaining of vibrational spectra at the electrode-solution interface *in situ*, and should be suitable for the structural determination of a variety of catalytic, adsorbed, and short-lived solution-free intermediates formed at such interfaces.

ACKNOWLEDGEMENT

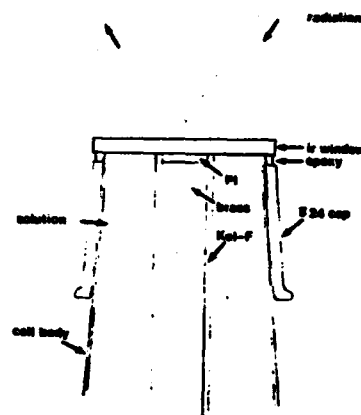
Part of this work was supported by the Office of Naval Research, Washington.

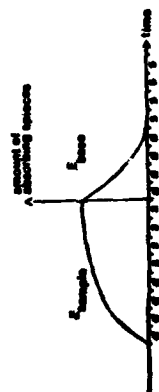
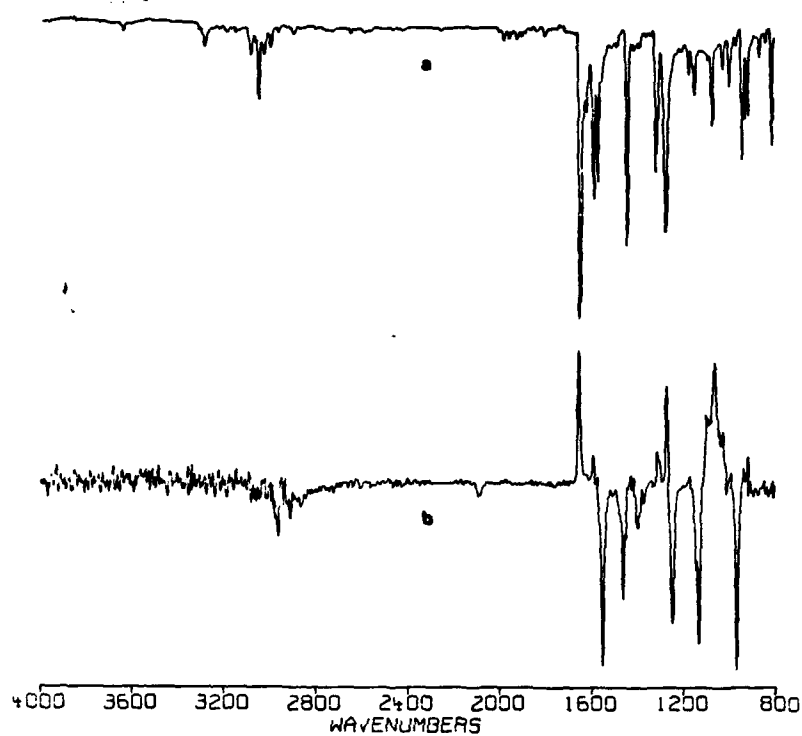
REFERENCES

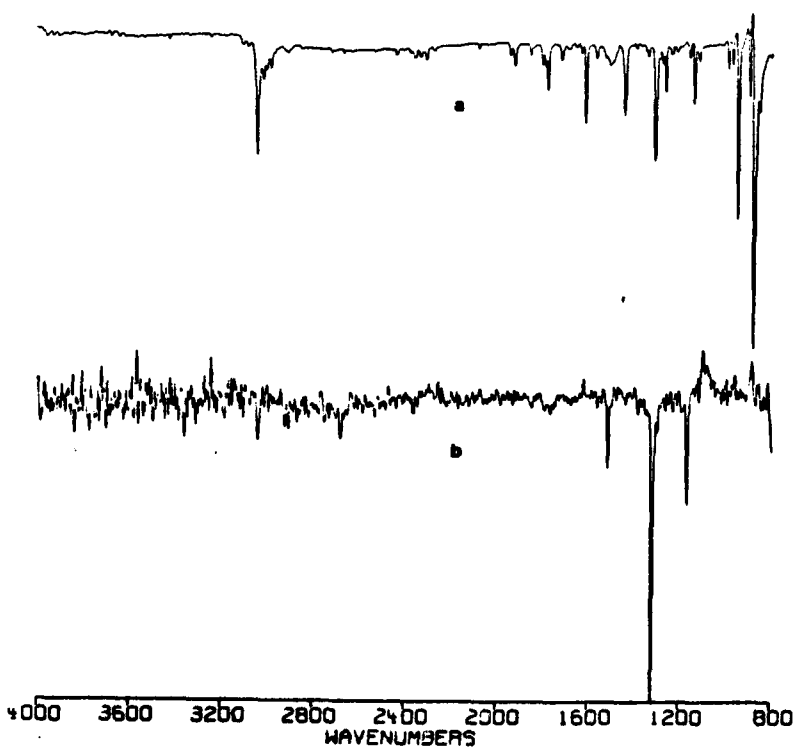
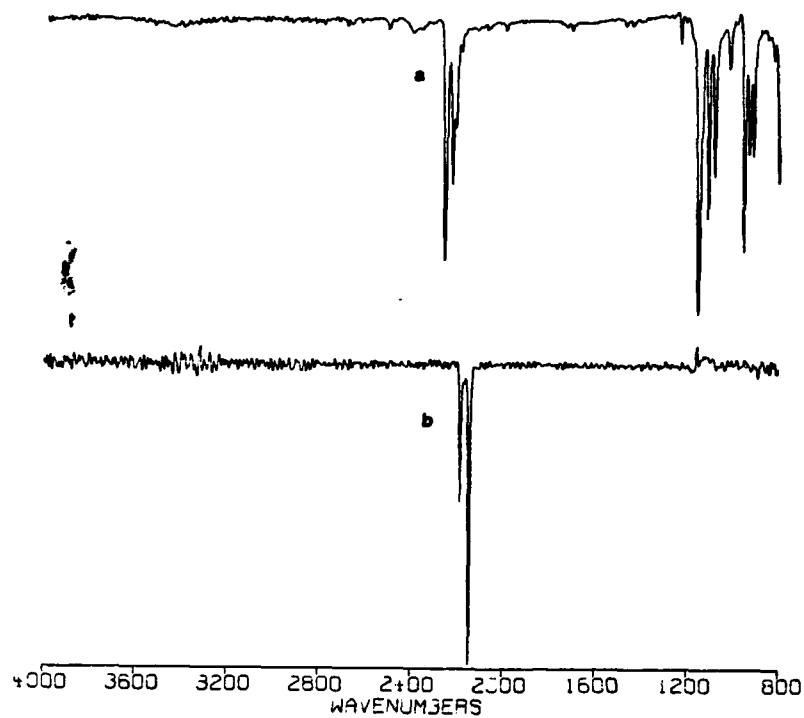
1. A. Bewick, K. Kunimatsu, and S. Pons, *Electrochim. Acta* **25** (1980) 465. A. Bewick and K. Kunimatsu, *Surf. Sci.* **101** (1980) 131.
2. T. Davidson, S. Pons, A. Bewick, and P.P. Schmidt, *J. Electroanal. Chem.* **125** (1981) 237.
3. J.W. Russell, J. Overend, K. Scanlon, M.W. Severson, and A. Bewick, *J. Phys. Chem.*, in press.
4. A. Bewick, K. Kunimatsu, J. Robinson, and J. Russell, *J. Electroanal. Chem.* **132** (1982) 329.
5. A. Bewick and J.W. Russell, *J. Electroanal. Chem.*, in press.
6. D. Beden, A. Bewick, K. Kunimatsu, and C. Lamy, *J. Electroanal. Chem.* **121** (1981) 243.
7. S. Pons, T. Davidson, and A. Bewick, *J. Electrochem. Soc.*, submitted.
8. A. Bewick, C. Gibilaro, *J. Electroanal. Chem.*, submitted.
9. S. Pons, T. Davidson, and A. Bewick, *J. Electroanal. Chem.*, submitted.
10. A. Bewick and K. Kunimatsu, *J. Electroanal. Chem.*, submitted.
11. A. Bewick, K. Kunimatsu, S. Pons, and J. Russell, *Anal. Chem.*, submitted.
12. M. Harrick, *Appl. Optics* **10** (1971) 2344.

FIGURE LEGENDS

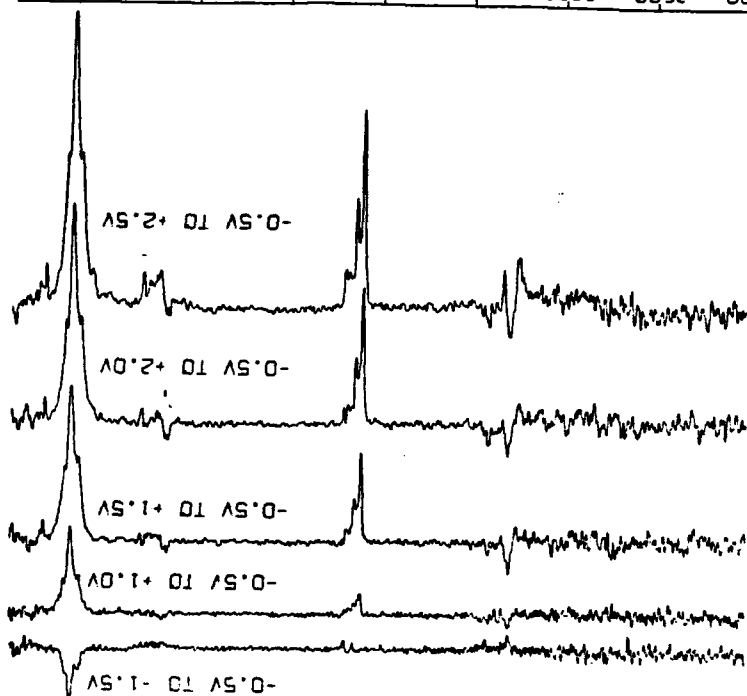
- (1) Cell cap and electrode tip configuration.
- (2) Timing for spectra acquisition. Points (d) represent spectra that are discarded, points (s) represent spectra that are saved and co-added. Diagram is for case where more absorbing species are present at high sampling potential.
- (3) a) Transmission spectrum of benzophenone. (b) Difference spectrum between -0.75 V and -2.50 V (10 mM benzophenone in 0.10 M TBAF in acetonitrile). Downward extending peaks are for the ketyl anion.
- (4) a) Transmission spectrum of anthracene. (b) Difference spectrum between -1.50 V and -2.50 V.
- (5) a) Transmission spectrum of tetracyanoethylene. (b) Difference spectrum between $+0.25$ and -0.25 V.
- (6) Difference spectra of anhydrous 0.10 M tetrabutylammonium tetrafluoroborate.
- (7) Same as Figure 6, except 0.10 M H_2O included.



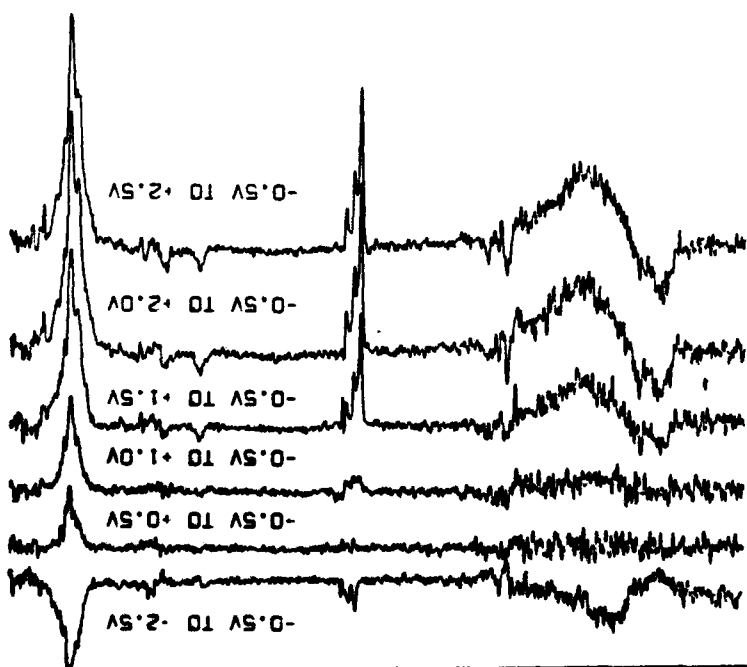




WAVENUMBERS 4000 3600 3200 2800 2400 2000 1600 1200 800



WAVENUMBERS 4000 3600 3200 2800 2400 2000 1600 1200 800



SP472-3/Al

472:GAN:710:anj
78a-72-008

SP472-3/Al1

472:GAN:710:an
78a-72-008

TECHNICAL REPORT DISTRIBUTION LIST, GEN

TECHNICAL REPORT DISTRIBUTION LIST, 329

	No. Copies		No. Copies
Office of Naval Research Attn: Code 472 800 North Quincy Street Arlington, Virginia 22217	2	U.S. Army Research Office Attn: CRD-AA-IP P.O. Box 1211 Research Triangle Park, N.C. 27709	1
ONR Western Regional Office Attn: Dr. R. J. Marcus 1030 East Green Street Pasadena, California 91106	1	Naval Ocean Systems Center Attn: Mr. Joe McCartney San Diego, California 92152	1
ONR Eastern Regional Office Attn: Dr. L. E. Peables Building 116, Section D 666 Summer Street Boston, Massachusetts 02210	1	Naval Weapons Center Attn: Dr. A. S. Ansar, Chemistry Division China Lake, California 93555	1
Director, Naval Research Laboratory Attn: Code 9100 Washington, D.C. 20390	1	Naval Civil Engineering Laboratory Attn: Dr. R. M. Drisko Port Hueneme, California 93401	1
The Assistant Secretary of the Navy (R&S) Department of the Navy Room 4E736, Pentagon Washington, D.C. 20350	1	Department of Physics & Chemistry Naval Postgraduate School Monterey, California 93940	1
Commander, Naval Air Systems Command Attn: Code 310C (H. Rosenwasser) Department of the Navy Washington, D.C. 20360	1	Scientific Advisor Commandant of the Marine Corps (Code 4D-1) Washington, D.C. 20380	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22304	12	Naval Ship Research and Development Center Attn: Dr. G. Bozeman, Applied Chemistry Division Annapolis, Maryland 21401	1
Dr. Fred Sealfield Chemistry Division, Code 4100 Naval Research Laboratory Washington, D.C. 20375	1	Naval Ocean Systems Center Attn: Dr. S. Yamamoto, Marine Sciences Division San Diego, California 92132	1
		Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1

	No. Copies		No. Copies
Dr. Paul Delahay Department of Chemistry New York University New York, New York 10003	1	Dr. P. J. Sunda Department of Chemistry University of Southampton Southampton SO9 5NH United Kingdom	1
Dr. E. Yeager Department of Chemistry Case Western Reserve University Cleveland, Ohio 44106	1	Dr. Sam Porosa Department of Chemistry Purdue University West Lafayette, Indiana 47907	1
Dr. D. H. Semion Department of Chemical Engineering Brigham Young University Provo, Utah 84602	1	Dr. Bryce W. Murray Department of Chemistry University of North Carolina Chapel Hill, North Carolina 27514	1
Dr. R. A. Marcus Department of Chemistry California Institute of Technology Pasadena, California 91125	1	Naval Ocean Systems Center Attn: Technical Library San Diego, California 92152	1
Dr. J. J. Amburn Bell Laboratories Murray Hill, New Jersey 07974	1	Dr. C. E. Hoeller The Electrochemistry Branch Materials Division, Research & Technology Department Naval Surface Weapons Center White Oak Laboratory Silver Spring, Maryland 20910	1
Dr. Adam Heller Bell Laboratories Murray Hill, New Jersey 07974	1	Dr. G. Goodman Glabe-Holm Incorporated 3757 North Green Bay Avenue Milwaukee, Wisconsin 53201	1
Dr. T. Eaton Lockheed Missiles & Space Co. Inc. P.O. Box 504 Sunnyvale, California 94088	1	Dr. J. Seachler Electrochimica Corporation Attention: Technical Library 2485 Charleston Road Mountain View, California 94040	1
Dr. Joseph Singer, Code 302-1 NASA-Lewis 21000 Brookpark Road Cleveland, Ohio 44135	1	Dr. F. P. Schmidt Department of Chemistry Oakland University Rochester, Michigan 48063	1
Dr. B. Brummer EIC Incorporated 53 Chapel Street Newton, Massachusetts 02156	1	Dr. F. Eichtel Chemistry Department Pennsylvania Polytechnic Institute Troy, New York 12181	1
Library F. R. Mallory and Company, Inc. Northwest Industrial Park Burlington, Massachusetts 01803	1		

SP472-3/813

472:GAN:716:44c
78472-608

SP472-3/A15

472:GAN:716:44b
78472-608

TECHNICAL REPORT DISTRIBUTION LIST, 359

	No. Copies		No. Copies
Dr. A. B. Ellis Chemistry Department University of Wisconsin Madison, Wisconsin 53706	1	Dr. R. P. Van Deyne Department of Chemistry Northwestern University Evanston, Illinois 60201	1
Dr. H. Wright Chemistry Department Massachusetts Institute of Technology Cambridge, Massachusetts 02139	1	Dr. E. Stanley Jones Department of Chemistry University of Alberta Edmonton, Alberta CANADA T6C 2G2	1
Larry E. Plew Naval Weapons Support Center Code 38736, Building 2906 Crane, Indiana 47522	1	Dr. Michael J. Weaver Department of Chemistry Michigan State University East Lansing, Michigan 48824	1
S. Babu DOE (STOE) 600 E Street Washington, D.C. 20545	1	Dr. P. David Rauh EIC Corporation 55 Chapel Street Newton, Massachusetts 02150	1
Dr. Aaron Held Brown University Department of Chemistry Providence, Rhode Island 02192	1	Dr. J. David Margerum Research Laboratories Division Hughes Aircraft Company 3011 Malibu Canyon Road Malibu, California 90265	1
Dr. R. C. Chudach McGraw-Hill Company Edison Battery Division Post Office Box 28 Blomfield, New Jersey 07003	1	Dr. Martin Fleischmann Department of Chemistry University of Southampton Southampton SO9 5NH England	1
Dr. A. J. Bard University of Texas Department of Chemistry Austin, Texas 78712	1	Dr. Janet Osteryoung Department of Chemistry State University of New York at Buffalo Buffalo, New York 14214	1
Dr. N. N. Nicholson Electronics Research Center Rockwell International 3370 Miraloma Avenue Anaheim, California	1	Dr. R. A. Osteryoung Department of Chemistry State University of New York at Buffalo Buffalo, New York 14214	1
Dr. Donald W. Ernst Naval Surface Weapons Center Code 8-33 White Oak Laboratory Silver Spring, Maryland 20910	1	Mr. James R. Noden Naval Underwater Systems Center Code 3632 Newport, Rhode Island 02840	1

TECHNICAL REPORT DISTRIBUTION LIST, 359

	No. Copies		No. Copies
Dr. R. Housh Naval Research Laboratory Code 6130 Washington, D.C. 20375	1	Dr. Bernard Spielvogel U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709	1
Dr. John F. Houlahan Shenango Valley Campus Pennsylvania State University Sharon, Pennsylvania 16146	1	Dr. Danton Elliott Air Force Office of Scientific Research Bolling AFB Washington, DC 20332	1
Dr. D. F. Shriver Department of Chemistry Northwestern University Evanston, Illinois 60201	1	Dr. David Athens Chemistry Department Rensselaer Polytechnic Institute Troy, NY 12181	1
Dr. D. B. Whitmore Department of Materials Science Northwestern University Evanston, Illinois 60201	1	Dr. A. P. S. Lever Chemistry Department York University Downsview, Ontario M3J1P3 Canada	1
Dr. Alan Bewick Department of Chemistry The University Southampton, SO9 5NH England	1	Mr. Maurice P. Murphy Naval Sea System Command 63832 2211 Jefferson Davis Highway Arlington, VA 20360	1
Dr. A. Hiy NAVSEA-5433 MC 94 2541 Jefferson Davis Highway Arlington, Virginia 20362	1	Dr. Stanislaw Sopch Naval Ocean System Center Code 6343 San Diego, CA 95152	1
Dr. John Kincaid Department of the Navy Strategic Systems Project Office Room 901 Washington, DC 20376	1	Dr. Gregory Farrington Department of Materials Science & Engineering University of Pennsylvania Philadelphia, PA 19104	1
M. L. Robertson Manager, Electrochemical Power Sonics Division Naval Weapons Support Center Crane, Indiana 47522	1	Dr. Bruce Dunn Department of Engineering & Applied Science University of California Los Angeles, CA 90024	1
Dr. Elton Cairns Energy & Environment Division Lawrence Berkeley Laboratory University of California Berkeley, California 94720	1		

TECHNICAL REPORT DISTRIBUTION LIST, 359No.
Copies

Dr. Micha Tomkiewicz
Department of Physics
Brooklyn College
Brooklyn, NY 11210

1

Dr. Lesser Blum
Department of Physics
University of Puerto Rico
Rio Piedras, PR 00931

1

Dr. Joseph Gordon II
IBM Corporation
K33/281
5600 Cottle Road
San Jose, CA 95193

1

Dr. Robert Sommano
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91103

1

DATE
ILME